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REDUCTION OF WHEEL UNBALANCE DURING DESIGN & MANUFACTURING BY REDUCING PROCESS VARIATION

A. Narendra Dhanrale B. Prof. Bharat Aldar, C. Sunil Bhatambrekar, D Prof. Pravin Pardeshi

***Abstract*—The unbalanced wheel rim vibrates, causing damage to itself and vehicle parts like suspension, steering parts and cabin. At certain speed when their own vibration frequency is equal to the rotation speed of the wheel rim the parts are at resonance stage and failed during operation. Research showed that the wheel, Tyre and its axle assembly had to be in a state of balance.The distribution of mass had to be even about the rotating centerline so that the resultant vibration is at a minimum. This had to be achieved during the designing & manufacturing process so that maximum service life could be achieved.**

As vehicles go faster, the effect of the unbalance is much more severe. A level of unbalance that is acceptable at a low speed is completely unacceptable at a higher speed. This is because the unbalance condition produces centrifugal force, which increases as the speed increases. It is the force that causes vibration of the surrounding parts. Prolonged exposure to the vibration results in damage, increased Noise & discomfort. Vibration can also be transmitted to adjacent part, affecting their accuracy or performance.

It is possible to make perfectly true wheel by tool room methods but the cost is beyond what customer willing to pay. The ultimate goal is to produce a wheel with as small unbalance as a economically feasible. So by controlling the process variation the level of unbalance within the acceptable limit.

***Index Terms*—Wheel Rim, Wheel Disc, Wheel unbalance, Wheel Imbalance**

I. INTRODUCTION

TYRESare mounted to fit a certain rim diameter. The purpose of the wheel is to connect the axle to the tyre and transmit forces from one to the other. A wheel essentially consists of two main parts: Rim and Disc. The rim receives the tyre. Its flanges keep the beads in place when the tyre is inflated as shown in Fig. 1. The two seats, usually inclined at 5° or 15° to improve the fitting. The drop centre is needed to enable mounting and dismounting of the tyre and its shape reinforces the rim structure.

The disc permits the attachment of the wheel to the vehicle hub. The disc and the rim are usually welded or riveted together permanently. Certain wheel types however, have adjustable discs allowing variable wheel track widths dependent upon the implement used or the farm work required.

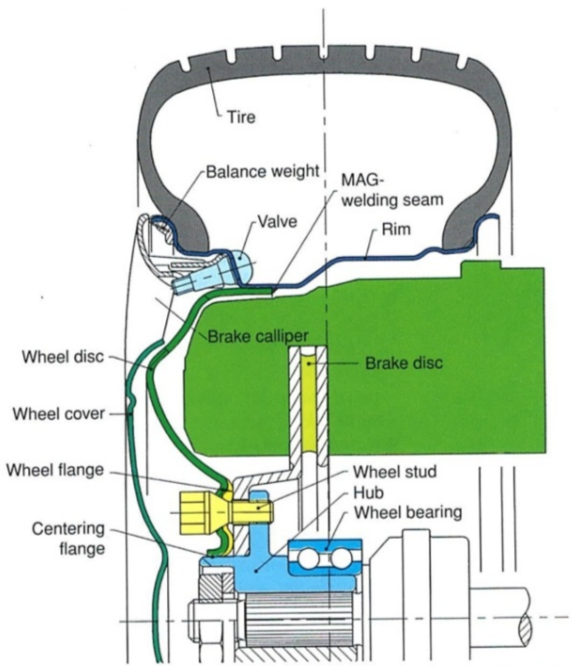

Fig. 1 Wheel Rim Assembly

A. *Types of Wheel Rim:*[1]

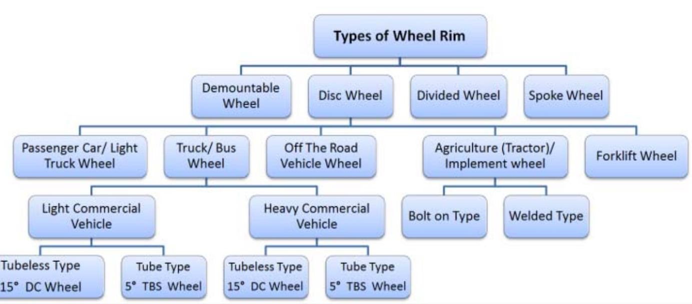

Chart 1 Types of Wheel Rim

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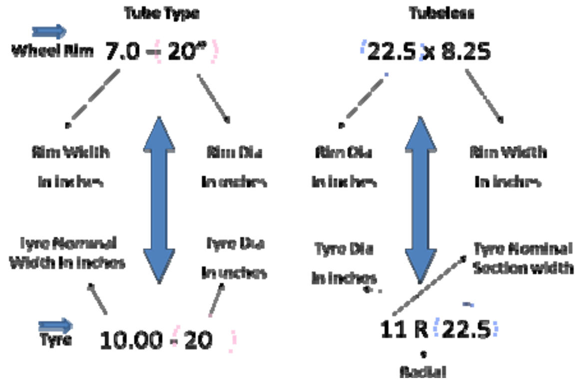
Narendra Dhanrale is with Department of Mechanical Engineering, Pune University, Zeal College of Engineering and Research, Pune, (e-mail: narendradhanrale@gmail.com).

Prof. Bharat Aldar is with Department of Mechanical Engineering, Pune University,Zeal College of Engineering and Research, Pune,

Sunil Bhatambrekar is Head Product Engineering, Kalyani Maxion Wheels Ltd, Gat No. 635, Village Kuruli, Chakan, Tal Khed, Dist. Pune, India.

Prof. Pravin Pardeshi is with Department of Mechanical Engineering, Pune University,Zeal College of Engineering and Research, Pune.

B. *Wheel Terminology:*[1]



C. *Wheel Sketches:*[1]

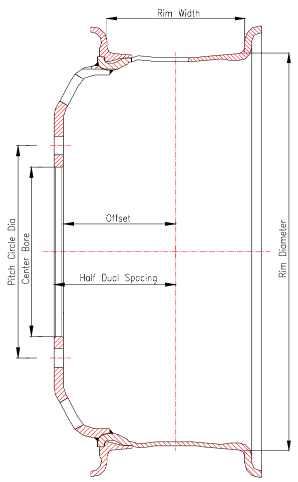


Fig. 2A
5° Tapered Bead Seat Wheel

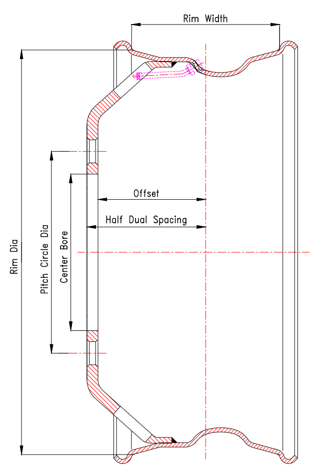


Fig. 2B
15° Drop Centre Wheel

D. *Typical Wheel Rim & Manufacturing Process:*

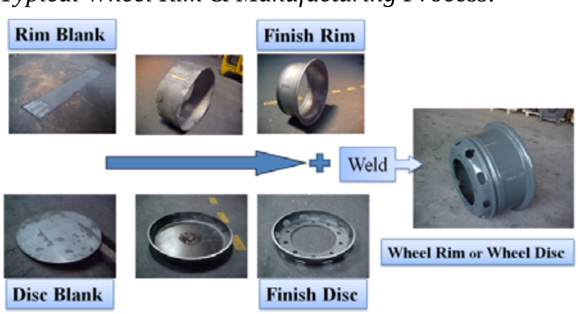


Fig. 3 Wheel Rim Manufacturing Process

Fig. 4 Typical Wheel Rim

II. Literature Review

A. *Effect of Unbalance on Vehicle Dynamics:*

Bixel[7] have studied the effect of sprung & unsprung mass determination without Vehicle Disassembly. Measurement of sprung & unsprung mass of vehicle using computer simulation. Measurement of a vehicle sprung mass Inertia parameters with benchmark test. Measured vehicle Roll/Yaw product of inertial Values by Vehicle Inertia Measurement Facility (VIMF).

The height of the sprung and unsprung mass lower as far as possible.

Srinvasan[5] have studied on the effect of wheel unbalance on vehicle Dynamics. Concept of Dynamic & Static Balancing of Wheel rim by experimental analysis.

The amount of unbalance increase, the vibrations increases.

B. *Balancing After Wheel Manufacturing:*

Jim[2]have studied on Dynamic Balancing Causes, Corrections and Consequences. Identifying and correcting the mass distribution in wheel which cause the unbalance. The wheel i.e. the mass had to be evenly distributed about the rotating centerline so that the resultant vibration was at a minimum.

Even mass distribution to be achieved during the manufacturing process.

C. *Relation Between Static & Dynamic Balancing:*

Tananko[4] investigate the statistical link between static & dynamic tire balance and show the specification on static balance can be relaxed without significantly sacrificing the dynamic balance specification. Relation between static & dynamic balancing is built & avoid dynamic balancing for Tyre. Monte-Carlo simulation is used to show that the tolerance on static balance can be relaxed without much effect on dynamic balance.

Dynamically balanced tire is always balanced statically.

In this seminar the work done in between effect of unbalance on Vehicle dynamics after wheel & tyre assembly &balancing after wheel manufacturing by adding balance weight on the tyre & rim assembly. Thecorrection in unbalance wheel or even mass distribution during wheel manufacturing is main aim of this seminar. The individual balancing of wheel rim part i.e. rim and disc during its different manufacturing stages.

The statically balance wheel rim will help to improve the dynamic balance of tyre & rim assembly together which is the final aim to reduce customer discomfort.

III. Unbalance In Wheel Rim[2]

Unbalance, an abstract concept with the general meaning of “lack of balance”. Unbalance in a machine designates the lack of equilibrium in the masses of a solid rotating about its axis.

Identifying and correcting the mass distribution and thus minimizing the force and resultant vibration is the technique known as balancing. The uneven distribution of mass about a rotor’s rotating centerline is Unbalance.

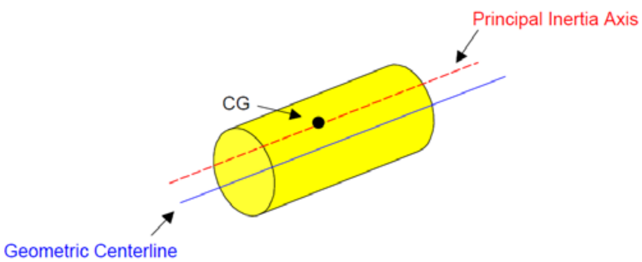


Fig. 5 Rotating Rotor

The rotating centerline being defined as the axis about which the rotor would rotate if not constrained by its bearings also called the Principal Inertia Axis (PIA). The geometric centerline being the physical centerline of the rotor as shown in Fig. 5. When the two centerlines are coincident, then the rotor will be in a state of balance. When they are apart, the rotor will be unbalanced.

Now apply a mass m (as shown in Fig. 6A) to the outside of the disc, at a distance r(mm)from the rotation axis, it is clear that when rotation at a speed of n (rpm), this mass m (gm) will generate a radial centrifugal force F (N) whose value is given by,

$$F = m\, r\, \omega^2$$

Where ω is the angular speed in radians per second $\omega = \frac{2\pi n}{60}$

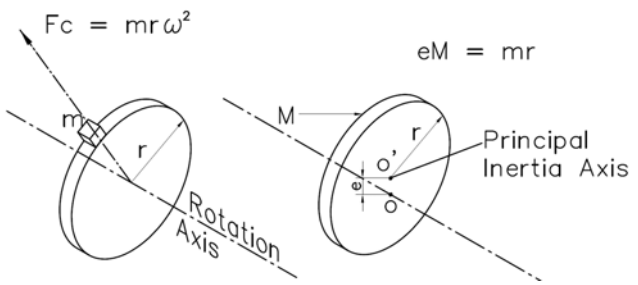


Fig. 6A Fig. 6B

Centrifugal force generated by an unbalance or by an eccentricity

Instead of an unbalance mass m, the same centrifugal force can be generated by an eccentricity e of the entire disc whose mass is M (as shown in Fig. 6B), such that:[3]

$$e\, M = m\, r = U$$

The product mr is called as unbalance (U) or imbalance.

Different types of unbalance can be defined by the relationship between the two centerlines. These include:

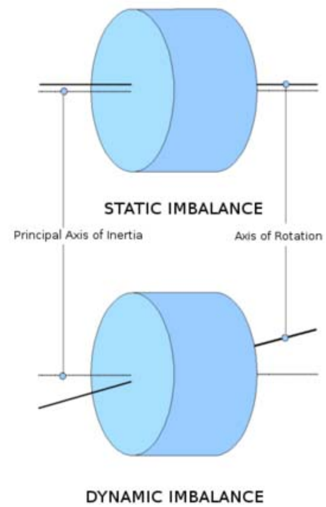


Fig. 7 Illustration of Static and Dynamic Unbalance

Static Unbalance – where the Principal Inertia Axis (PIA) is displaced parallel to the geometric centerline. (Shown above in Fig. 7)

Couple Unbalance – where the Principal Inertia Axis (PIA) intersects the geometric centerline at the center of gravity (CG).

Dynamic Unbalance – where the Principal Inertia Axis (PIA) and the geometric centerline do not coincide or touch.

A wheel is in dynamic balance, then it is also in static balance. However, a wheel can be in static balance without necessarily being in dynamic balance.[4]

IV. Causes Of Unbalance In Wheel Rim

In automobile, balancing addresses unbalances throughout the entire rotating assembly, tyre, wheel, brake, hub etc. as shown in Fig.8[6].

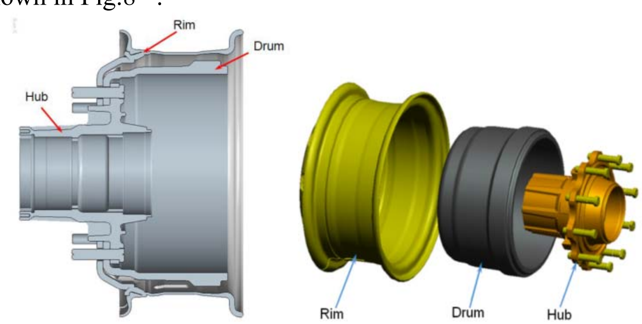


Fig. 8 Drive Unit Assembly

Sprung mass (or sprung weight) is the portion of the vehicle's total mass that is supported above the suspension. The mass of the components suspended below the suspension components including the wheels, wheel bearings, brake rotors, callipers, which are part of the vehicle's unsprung weight. The unsprung weight of a wheel controls a trade-off between a wheel's bump-following ability and its vibration isolation. Bumps and surface imperfections in the road cause tyre compression—which induces a force on the unsprung weight[7].

Bent wheels and wheels with damaged center bore & stud holes are other common causes of vibration and shimmy. It is important to remember that round and balanced are two different things. For instance an out of round wheel can be balanced. A square block could also be balanced, but it will roll with vibration.

A. Causes of Unbalance in Wheel rim while Designing & Manufacturing

Many causes are listed as contributing to an unbalance condition. In the manufacturing process, if proper care is taken to ensure that flow forming and machining is concentric, then it follows that the two axis will coincide and the assembled parts will be in a state of balance. Following are causes as per design & manufacturing,

a. Rim Unbalance:
   1. Rim notching
   2. Thickness Variation
   3. Flange height & width variation
   4. Gutter tip thickness variation
   5. Gutter groove depth variation
   6. Flow forming thickness variation
   7. Run-out value & zone
   8. Butt weld thk. Variation
   9. Butt welding mismatch
   10. Rim Width Variation
   11. Valve hole / Valve slot

b. Disc Unbalance:
   1. Stud Hole Concentricity w.r.t. Outer Dia.
   2. Weight of Valve passage/ valve hole
   3. Disc thickness Variation
   4. Outer Dia. machining
   5. Extra holes
   6. Disc height Variation

c. Ring Unbalance:
   1. Section Thickness Variation
   2. Section Length Variation
   3. Weight of removal slot
   4. Position of end gap
   5. Weight due to end gap
   6. Ovality

d. Assembly Unbalance:
   1. Radial Run-out
   2. Bore Concentricity w.r.t. Stud Hole
   3. Internal / External Weld
   4. Thk. Variation (uneven machining)
   5. Combined Run-out at Rim & Ring
   6. Lateral Run-out
   7. Welding Overlap
   8. Position of weld Overlap
   9. Deformation of wheel due to rough handling by operator

e. Design Unbalance:
   1. Assembly CG
   2. Dia. / width ratio
   3. Rim CG
   4. Wheel Dia. & weight
   5. Offset variation

f. Process / Rework Unbalance:
   1. Butt weld edge mismatch
   2. Welding uneven
   3. Mating Part variation

g. Unbalance Due to Mating Parts:
   1. Valve weight & Position
   2. Balance weight
   3. Valve guard weight
   4. Tyre (Unbalance, weight, Dia.etc.)
   5. Other parts like clip, safety pin, o-ring etc.

B. Assembly Causes in Vehicle

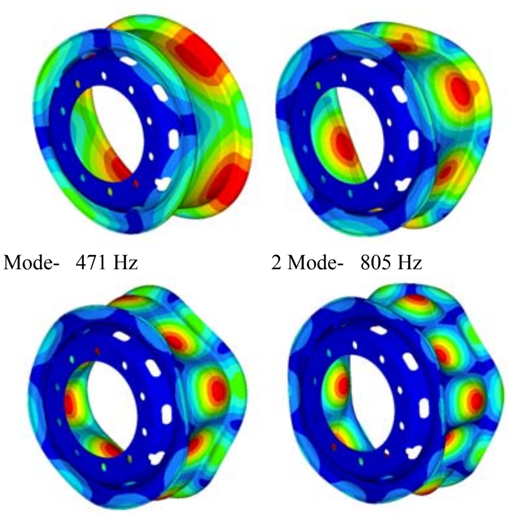
There are many reasons due to which unbalance occurs. Principle among these is a stack up of tolerances. When a well-balanced rim and a well-balanced disc are united, the necessary assembly tolerances can permit radial displacement, which will produce an out of balance condition. Also mounting tolerances while assembling with vehicle &tyre.

C. Working Conditions Causes

When a component has been in service for some time, various other factors can contribute to the balance condition. These include corrosion; wear, distortion, and deposit build up. Deposits can also break off unevenly, which can lead to severe unbalance. Also other components which are assembled with wheel like hub, brake drum etc. unbalance add on wheel unbalance.

V. Modal Analysis of Wheel Rim

Natural frequency of wheel rim is find by modal analysis. FEM model with fixed boundary conditions is used for all degrees of freedoms at bolt holes. The natural frequency of wheel rim by Modal Analysis of Finite Element Modelis calculated. Four mode shapes and corresponding natural frequencies whichare shown in Fig. 9.



1 Mode- 471 Hz   2 Mode- 805 Hz

3 Mode- 1282 Hz   4 Mode- 1591 Hz

Fig 9: Modal Analysis of Finite Element Model

For First Mode, Natural frequency is 471 Hz. Also at 120 Km/h vehicle speed, the calculated operating frequency is about 9.815 Hz which is very much lower compared to the natural frequency. So during operation of vehicle the parts are not cross natural frequency and resonance will not occur.[5]

VI. Design Unbalance Calculations

The unbalance mass or asymmetry on the rotating part which create unbalance, but these features are necessary as application requirement which are unavoidable.

Wheel Design Unbalance is divided into

- Fixed Design Unbalance (Due to asymmetry like Valve slot, extra holes etc.)
- Variable Design Unbalance (Due to thickness variation, uneven material removal etc.)

To out the design unbalance in the wheel rim as follows,

$$F = m\, r\, \omega^2 \& F = U\, \omega^2$$

Total Design Unbalance (U) = mass (m) x Radius (r)
Where,

m= Unbalance Mass

r= radius at which this mass is located

Basically the design features which create unbalance for example valve slot or valve hole 82mmx15mmx5.6mm(approx.mass=54 gm) at the radius is 25cm. So Design unbalance due to valve slot is,

= 54 gm x25 cm
= 1350 gm-cm

The center bore is the most preferred location for clamping & locating as it gives higher accuracy because there is no influence of pitch circle diameter errors and variations in bolt holes size,still there is a tolerance of 0.2mm, so the center line or rotational axis is shift by 0.2mm. Now consider the axis shift by e=0.2mm i.e. 0.02 cm and wheel weight without ring is 38kg the unbalance is,

$$e\, M = m\, r = U$$
$$U = 38000 \text{ gm} \times 0.02 \text{ cm}$$
$$= 760 \text{ gm-cm}$$

760gm-cm unbalance is created only by center bore tolerance of 0.2mm. To compensate this unbalance need to add 30.4 gm weight at the opposite location at 25cm.

Software is developed to calculate unbalance values. The screen shot is shown in Fig. 10.

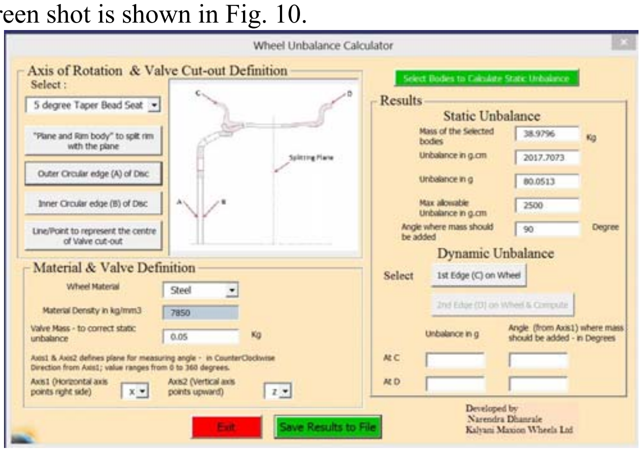


Fig 10: Unbalance Measurement Software Screen

To calculate the unbalance using a software, wheel rim 3D model in .igs format is used. By giving the attachment face location i.e. center bore, the software calculate unbalance in gm-cm. In this software with the help of Catia macro the accurate weight and position of the geometry which create unbalance is calculated. The static unbalance for 7.5-20 wheel rim is 2017.7 gm-cm calculated by this software.

The design unbalance itself on the higher side. So need to compensate this design unbalance by adjusting the process variation in such a way that it will reduce the final unbalance.

VII. Experimental Unbalance Calculations

A. Experimental setup

The CEMB C215 for wheel 16” to 24”Balancing machine is used to measure the unbalance values as shown in Fig. 11. The wheel rim is mounted on the disc attachment face on the adapter & quick cone lock nut which will proper centering to the wheel rim at center bore.

Fig 11: Balancing Machine setup for 7.5-20 wheel

B. Experimental Procedure

For 7.5-20 wheel rim some features which create unbalance i.e. valve slot, milling slot for valve passage.

The wheel is fixed without side ring to spindle of wheel balancing machine by use of quick cone lock nut. Quick cone lock nut ensures fast mounting and fast removal of wheel rim. Wheel balancing machine is switch on.

The spindle is made to rotate at speed of 400 rpm.

The rotation of the spindle is stopped.

Wheel balancing machine determines the size of weights and where to locate weight on the wheel.

The size of the weight and location of the weight to be placed is shown on the monitor of the wheel balancing machine.

The weight is recorded to rim at exact location which is shown on the monitor. And wheel is removed from the spindle of wheel balancing by the use of quick cone lock nut.

Measure the static unbalance for 20 wheel rims by balancing machine and record, the results are plotted is shown in Fig. 12,

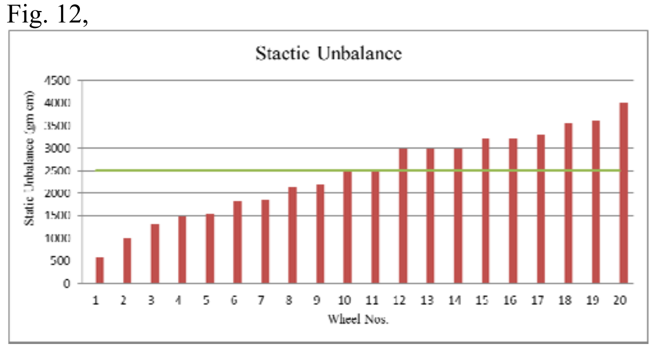


Fig 12:Static Unbalance for Wheel Rims

The Fig. 12 Static Unbalance Vs Wheel no. shows, unbalance in 50% wheels are out-off specifications i.e. above 2500 gm-cm (Specified as per IS 1940-1). In static unbalance measurement, contribution of design unbalance of this wheel rim without ring is 2065 gm-cm. So to avoid rejection after manufacturing the wheel rim with higher static unbalance, the process variation also need to consider. This process variation will increase the unbalance if mass distribution is opposite to valve slot & if it is near the valve slot it will reduce the unbalance. So measured the uneven distribution of mass during process and arrange that mass in such a way that it will optimize the final product unbalance.

During assembly the main operation is welding rim & disc. During welding process at the start & end the crater is created at overlap which add mass on the wheel rim. Arrange the welding position in such a way that the welding overlap will compensate the design unbalance which was created by valve slot & milling at valve passage. Some samples with different welding positions are made for internal & external overlap. By balancing machine again the unbalance weight & location are recorded.

VIII. Result & Discussions

The improvement in the unbalance value by arranging the internal and external welding position near the valve opening, the reading are shown in Fig. 14 Sample no. 2.5 (Lot 2 i.e. modified lot sample sr. no. 5) shows unbalance valve 1980 gm-cm in which the welding position at 45° from the valve slot. As against sample no. 1.4 (Lot 1 i.e. randomly selected samples from production sample sr. no. 4) where the welding position is about 180 deg. w.r.t. valve slot. The unbalance value is 3300 gm-cm. The results are shown in Table 1 & plotted in Fig. 14.

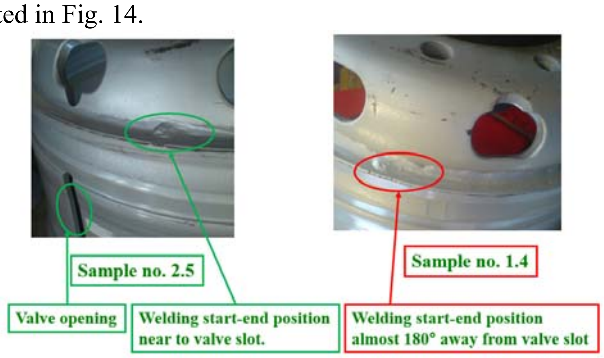


Fig 13: External welding start position w.r.t. valve slot

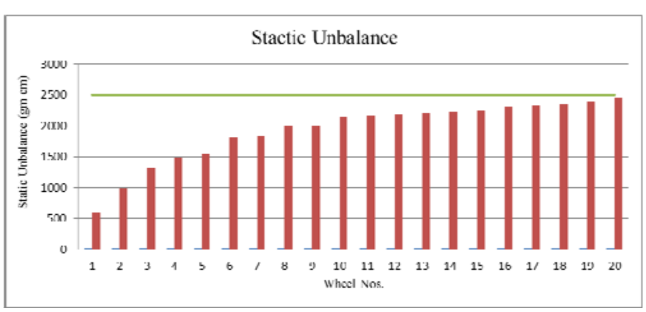


Fig. 14: Static Unbalance after welding overlap position correction

TABLE I
RESULT TABLE

Sr. No.	Wheel Rim	Static Unbalance (gm-cm)
1	Design Unbalance from Calculations	2065
2	Design Unbalance from Software	2017.7
3	Experimental Value after welding position adjustment	1980

The unbalance values are well within the acceptable limit.

Conclusion

Operating frequency of 7.5-20 wheel is far below the Natural frequency. No possibility of resonance in wheel during operation.

From the result Table 1 it is observed that the design and experimental values are well within the specifications and acceptable. But the trend of 50% wheels are very near to the acceptable limit i.e. 2500gm-cm. So need to work on the other causes also which create unbalance.

All rotating parts needs to be in a state of balance to ensure smooth running when in operation. Modern technology allows for accurate balancing of wheel rim in the workshop but it affect the cost of product.

Acknowledgment

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Mr. Narendra Dhanrale is graduate in Mechanical Engineering from Pune University. He is pursuing his postgraduate in Mechanical Engineering. With specialization in Design Engineering.